

Topological Synthesis of Tree Shaped Structures Based on a Building Blocks Hypothesis

Przemysław Miazga

Institute of Radio Electronics, Warsaw University of Technology, Warsaw, Poland

Abstract—In this paper a new approach to evolutionary controlled creation of electronic circuit connection topology is proposed. Microwave circuits consisting of a tree like connection of ideal transmission lines are considered. Assuming that a reasonable number of transmission lines in a tree network ranges from 10 to 100, the number of connection combinations is immense. From the engineering practice comes the hypothesis that any device can be decomposed into some functional building blocks consisting of one to dozen transmission lines. The variety of linking combinations in a tree with a limited depth is confined to hundreds or thousands of shapes. Therefore we can decrease the dimensionality of research space, applying evolution to building blocks only. Evolutionary algorithm (EA) which processes simultaneously the population of λ functional blocks and population of μ circuits is proposed. A μ, λ selection scheme with tournament together with specific encoding of solutions, and custom operators is implemented. The μ, λ, α EA was tested on an example of the design of a microwave transistor matching circuit.

Keywords—evolutionary algorithm, matching networks, minimax algorithm.

1. Impedance Matching Problem

The key issue in microwave circuit design is the matching problem. Microwave power, generated by sources (e.g., AC voltage generator) should be delivered to loads (e.g., antenna, microwave oven) with minimal losses, in the specified frequency band. Both the source and the load are characterized by their *admittances* $Y_g(f)$ and $Y_l(f)$, respectively. Admittances, in general, are complex numbers, with real and imaginary parts called *conductance* and *susceptance*, respectively. In the ideal case of perfect matching, without losses, it holds:

$$Y_l(f) = Y_g^*(f). \quad (1)$$

The matching network, shown in Fig. 1, is used to transform load admittance to fulfill condition (1).

Frequently, for passive circuits, source *susceptance* is small and can be neglected, while source *conductance* is constant. The procedures for matching some real to real admittance are well known [1]. The general problem of complex admittance matching is very hard to solve. Practically, only numerical optimization can be applied in that case. In general, load *susceptance* should be compensated,

and load *conductance* should be transformed to source *conductance*.

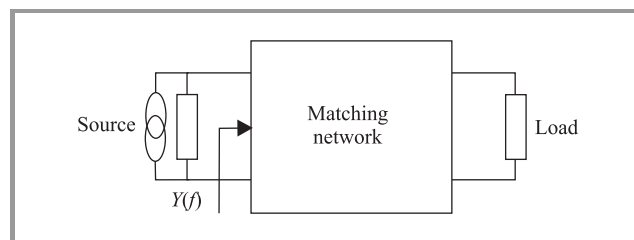


Fig. 1. General representation of a two-port matching network.

The quality of a device is usually defined by means of power loss through an *input reflection coefficient*. The *reflection coefficient* equals the square root of the ratio of power delivered to the load to power generated by the source. Assuming that transformed input admittance is equal to $Y(f)$, *reflection coefficient* $\Gamma(f)$ is given by:

$$\Gamma(f) = \frac{Y_g^*(f) - Y(f)}{Y(f) + Y_g^*(f)}. \quad (2)$$

In order to design an optimal circuit, the following minimax problem should be solved:

minimize (by changing parameters of elementary blocks)
 { **maximum** of $|\Gamma(f)|$ in the given frequency band } .
 (3)

High frequency (from megahertz to terahertz) impedance matching networks (which are mostly used in amplifiers and splitters) are usually designed as a cascade connection of elementary blocks (shown in Fig. 2), mostly uniform transmission lines [1]. The number of elementary blocks of the cascade is set initially. Only transmission line parameters undergo optimization. The cascade transmission device is usually easy to design, although expensive in manufacturing, for it needs thin and long substrate and case.

More compact, lightweight packaging can be used when the circuit is synthesized as a hybrid structure, which example is shown in Fig. 3.

Intuitively thinking, a wider frequency band and compactness can be achieved with a branching-out, tree-like connection of transmission lines. An example of the tree matching network is shown in Fig. 4.

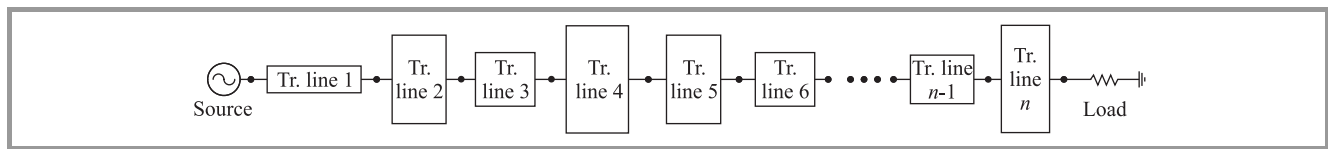


Fig. 2. Cascade two-port matching network.

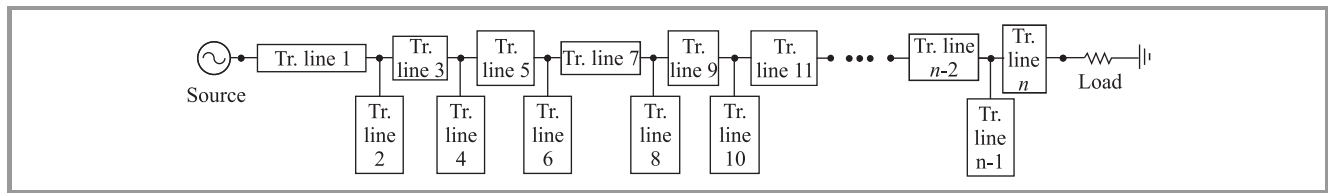


Fig. 3. Hybrid two-port matching network.

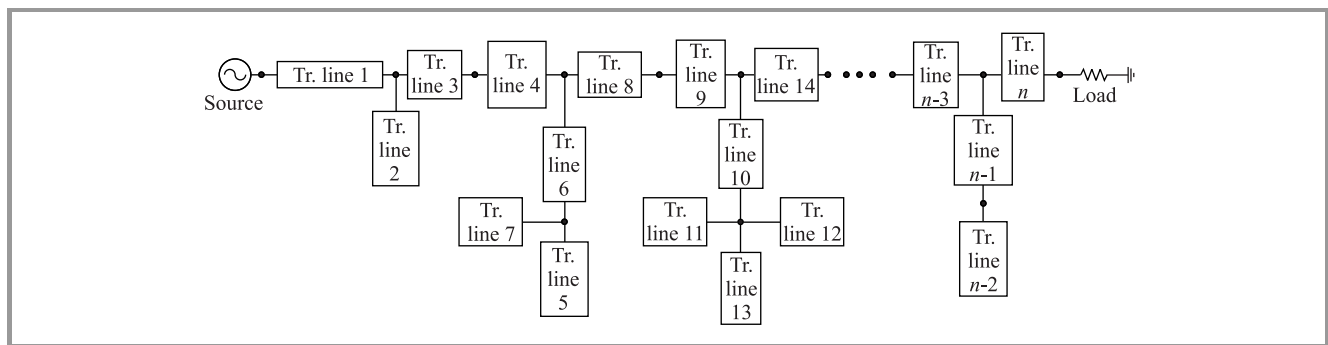


Fig. 4. Tree two-port matching network.

2. Topological Synthesis of a Tree-Shaped Structure

Evolutionary algorithm (EA) can be used as a very efficient tool for topological synthesis of tree devices. It produces the shape of a tree, which parameters (impedances and lengths of a uniform transmission line) are further optimized by a mini-max algorithm. In [2], EA with problem specific evolutionary operators, operating on a tree, was presented. The algorithm was based on the $\mu + \lambda$ selection scheme together with specific encoding of solutions. Each allele was coded as a node of the tree with links to connected blocks (nodes). Evolutionary operators: perturbation, contraction, expansion were designed to operate with a single allele (transmission line or line termination) uniformly within the whole tree. The recombination was defined in a similar way to a one-point crossover. The algorithm was tested with success. Several new topologies for networks matching real source to real load were generated.

Wideband transistor matching usually imposes higher demands than in the case of real-to-real admittance matching. The real part of CHH 27060 transistor input impedance, shown in Fig. 5, ranges from 200 to 377 Ω . Assuming that the imaginary part was compensated, we must match the varying $\sim 300 \Omega$ load to the 50 Ω source in a 4–6 GHz band. It's like solving a very hard NP-complete problem.

Very good matching (with a reflection coefficient better than 0.1) is achieved in a very narrow frequency band like 5.45–5.55 GHz. In practice, the reflection coefficient better than 0.31 (one tenth of power lost) is sufficient.

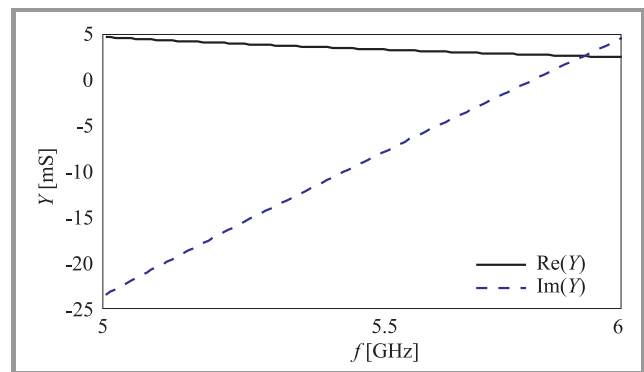


Fig. 5. CHH 27060 transistor input admittance.

Tree $\mu + \lambda$ EA [2] applied to the CHH 27060 complex load matching usually fails. This phenomenon is mostly caused by the failures of a fitness evaluation method. The presence of poles in the circuit response characteristics causes premature convergence of a mini-max solver. Therefore local optimization should be performed initially for a very narrow frequency band, in order to find a feasible starting point. Later, the frequency band can be widened, unless the quality criteria (acceptable power loss) is fulfilled.

Still, after the implementation of fitness evaluation with an expanding bandwidth, $\mu + \lambda$ EA saturates after dozen of generations and the final solution is not promising. EA very seldom generates branching out structures. More likely, EA ends with a cascade or hybrid topology. The change to μ, λ selection scheme improves convergence, although generated topologies are still unsatisfactory.

The averaged results of 12 ES simulations are shown in Figs. 6–8. The bandwidth starts with 20% of a desired frequency band (5.4–5.6 GHz). After the success of mini-max optimization (when fitness is below acceptable power loss level) the frequency range is incremented by 10% (± 0.1 GHz). The chromosome is qualified according to its bandwidth. In the case of equal bandwidths of the circuit, the value of the reflection coefficient takes the role of fitness (the lower, the better).

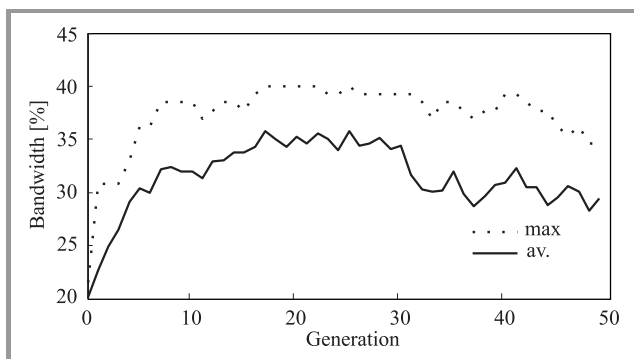


Fig. 6. Maximal and average relative bandwidth versus generation number.

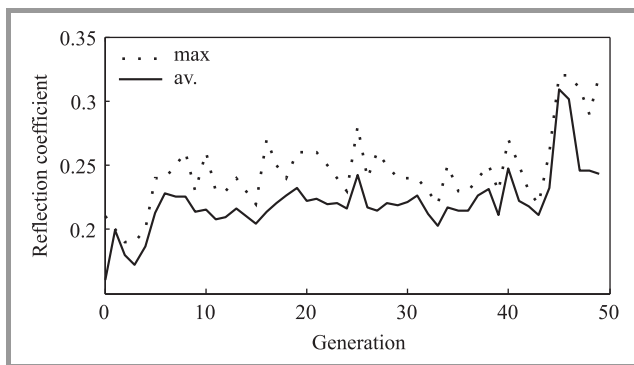


Fig. 7. Maximal and average reflection coefficient versus generation number.

Initially, the device is growing. At about 20th generation the number of transmission lines is very close to its limit (100). After that time neither bandwidth nor power loss is improving. On the contrary, we can observe circuit “collapse” and loss of performance. Analyses of topologies generated by EA show that initially various tree structures are generated. However, later cascade type topologies are growing faster than branches. The structures created by mutation and recombination operators from “branching out” trees are often unusable due to the presence of poles and therefore eliminated. After 20–30 generations only cascade

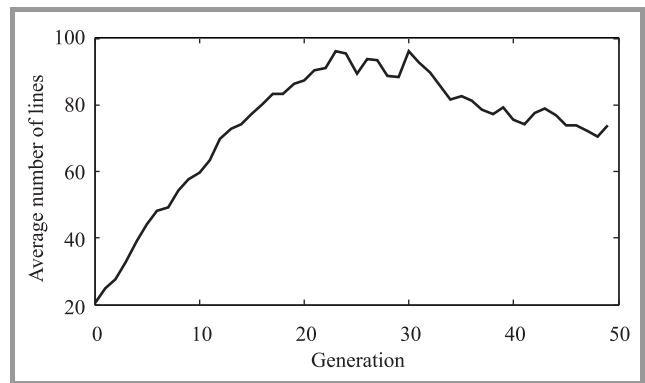


Fig. 8. Average number of transmission lines in chromosome versus generation number.

or hybrid individuals are processed. At the end of optimization, high contraction pressure (the optimal number of transmission lines is assumed to be 50) causes population degradation.

3. Building Block Hypothesis of a Tree Shaped Structure

The tree-shaped matching circuit can be decomposed to the structure shown in Fig. 9. It consists of a main path connecting input (source) with an output (load), called stem, and branches connected to the stem.

In every electronic device some parts of the circuit play different roles. The stem is usually responsible for matching the real part of load admittance, while branches add some susceptance compensating load susceptance. A sub-circuit connected with a load is usually responsible for output matching. In more complicated devices, like a diplexer (a multiband filter-splitter), every branch is responsible for transmission in one frequency band. Each block plays its role. We may expect that the whole circuit can be assembled from more or less complex building blocks.

Sensitivity analysis shows also that some blocks strongly affect some aspects of overall performance, while others do not. Uniformly acting evolutionary operators are in this case strongly overloaded. Therefore building blocks should be divided into two classes: stems and branches. Evolutionary operators should be “tailored” to the role of the block.

An evolutionary algorithm, with μ, λ selection, based on a concept of building blocks, was created. The μ, λ, α EA processes two sets of circuits, the first set consisting of stems and branches, called block library, and the second – population of chromosomes. A chromosome consists of one stem and several branches taken from the block library. The number of blocks in the library is limited to some number α . The initial population and the block library are generated randomly.

Specialized evolutionary operators are used during optimization. There are two types of mutation. The first one

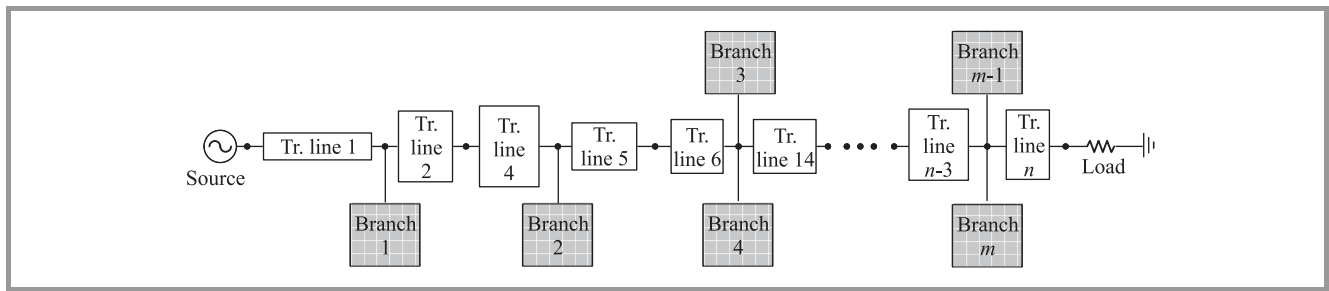


Fig. 9. Steam/branch topology.

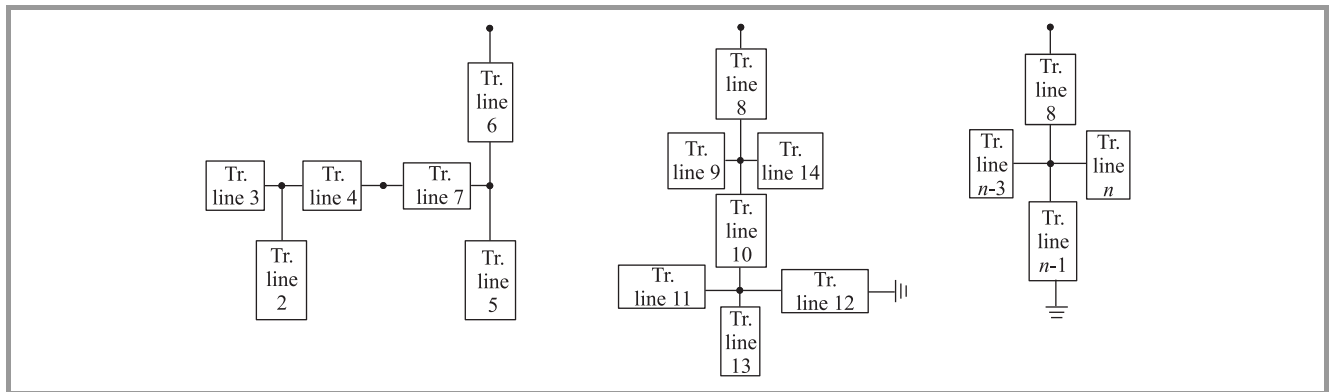


Fig. 10. Various branch topologies.

flips characteristic impedance of the line from low to high impedance. The second type, which is called meta-mutation, exchanges the whole side branch with the one randomly drawn from the library. Recombination (similar to the two point crossover) can be used only for two stems or two branches.

Contraction or expansion removes or adds a single transmission line, respectively. Contraction and expansion probabilities depend on the number of transmission lines in the circuit in order to keep the circuit size within a 10 to 100 elements range. Meta contraction or expansion removes or adds the whole branch (which is drawn from the library), respectively.

Newly created blocks are copied to the offspring library. Parental chromosomes and library blocks are either erased (μ, λ strategy) or copied ($\mu + \lambda$ strategy) to the offspring population and the offspring library, respectively.

Population is evaluated with local optimization [2], using a mini-max solver. Each chromosome is assigned a reached bandwidth and a final reflection coefficient. Library blocks are also qualified. Each one is assigned fitness equal to the fitness of the best chromosome, where the block is used. Two or three member tournament is used for selection, separately within the population and the library. The blocks, used in population after selection, are automatically preserved.

Practical realization of the algorithm ($\mu = 16$, $\lambda = 64$, $\alpha = 64$) applied to the CHH 27060 transistor matching shows overwhelming superiority of the functional blocks approach. A relative bandwidth of 50% (5.25–5.75 GHz)

is frequently achieved after 15–16 generations for acceptable power loss. Usually, after 4–5 generations the population consists mostly of very good individuals (with 40% or more relative bandwidth).

An example of one of the generated topologies and its frequency response are shown in Figs. 11 and 12, respectively.

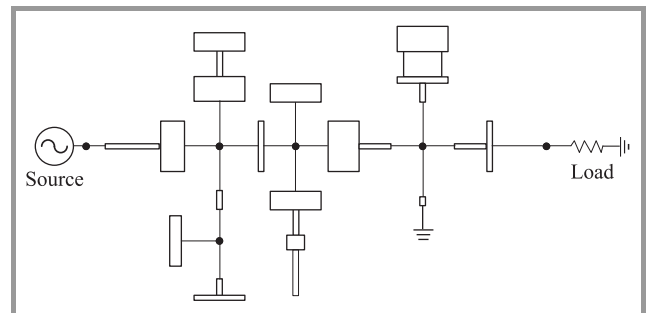


Fig. 11. Example of 5.25–5.75 GHz matching circuit.

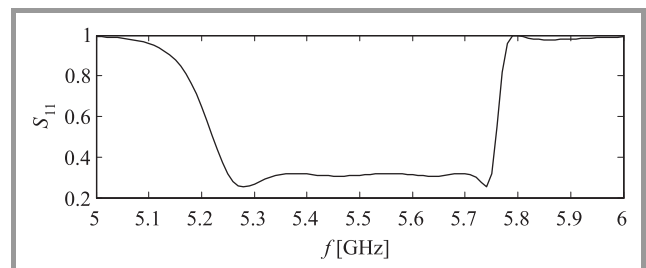


Fig. 12. 5.25–5.75 GHz matching circuit frequency characteristic.

It was observed that branches stored within the library are, after the initial period, only slightly modified. The tree topology usually remains untouched, only the number of cascaded sections in arcs is changing. Most likely, all improvement is achieved thanks to stem expansion and meta-mutation. It seems also that some blocks behave better at a given location inside the network than at another. Therefore we may suspect that EA can be used for the extraction of functional blocks responsible for a certain aspect of circuit behavior. Topologies from classes of functional blocks extracted with EA can be then used in initializing the block library.

References

- [1] G. Matthaei, L. Young, and E. M. T. Jones, *Microwave Filters, Impedance Matching Networks and Coupling Structures*, Artech House 1980, pp. 365–372.
- [2] J. Arabas and P. Miazga, “Computer aided design of a layout of planar circuits by means of evolutionary algorithms”, *J. Comput. Inform. Technol.*, CIT 7, pp. 61–78, 1999.



Przemysław Miazga received the M.Sc. and Ph.D. degrees in Electronics at Warsaw University of Technology in 1980 and 1989, respectively. Since 1989 he has been Assistant Professor at the Institute of Radio Electronics, Warsaw University of Technology. His research interests comprise methods of computer aided design, including

modeling and analysis, of microwave and digital circuits and networks, and optimization methods. He is an author of over 40 publications. As an academic lecturer he conducts classes and laboratories on microwave techniques, electromagnetic field theory, antennas, optimization techniques and digital circuits. He is the main author of QW-Optimizer (www.qwed.eu).

E-mail: p.miazga@ire.pw.edu.pl

Institute of Radio Electronics

Warsaw University of Technology

Nowowiejska st 15/19

00-665 Warsaw, Poland